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A Diamond Diffraction Grating Formed via Ion Implantation

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Abstract—A fundamentally new way of fabricating a diffraction grating on a surface of diamond via ion (boron) implantation through a superimposed mask is proposed. It is found that graphitization occurs during ion irradiation in unmasked areas in the near-surface region. This graphitization results in the swelling of the surface layer and the formation of a phase periodic structure.

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INTRODUCTION

In the 1990s, Nobel Laureate A.M. Prokhorov spearheaded the development of diamond optics (a separate area of applied research related to integral optics) in Russia [1]. Diamond is a natural choice for the role of an optical material, since it offers unique radiation resistance and high heat-transmission capacity. Diamond optical elements with their wide window of transparency from 0.2 to more than 20 μm remain operational in aggressive chemical environments and upon extreme variations in temperature. Diamond is now used to fabricate a variety of diffraction optical elements (DOEs), e.g., gratings, kinoforms, focusators, and correctors [1, 2]. Diamond DOEs can be used to transform the radiation of high-power (up to 20 kW cm^{-2}) CO_2 lasers [3, 4], to fabricate photon-crystal cavities for quantum mechanisms of data storage and accumulation [5], to guide radiation fluxes in X-ray optics (with, e.g., diamond Bragg mirrors (reflecting diffraction gratings) that have reflection coefficients of ~100% [6]), and so on.

Different processing techniques, e.g., electron lithography [7], the deposition of colloidal microspheres [8], irradiation with high-intensity pulses from an excimer laser [9], and etching in a gas flow [10], are used in fabricating periodic DOEs. A new approach to fabricating diamond DOEs that employs ion implantation through a metallic mask on a diamond surface is proposed in this work. This approach was used earlier to form DOEs on softer dielectric, polymer, and porous semiconductor substrates implanted with noble-metal ions [11–13]. Boron ions were chosen in this work, since they are often used for diamond doping in the microelectronics industry [14].

EXPERIMENTAL

To form a DOE, the polished surface of synthetic optically transparent colorless diamond was implanted with boron ions having energy E = 40 keV through a surface mask (a nickel–copper mesh with square cells 40 μm in size) on the ILU-3 accelerator. The radiation dose was $D = 1.3 \times 10^{18}$ ion cm^{-2} at current density J = 15 μA cm^{-2} in the ion beam. The local morphology and the structure of the implanted diamond surface were studied using a Merlin (Carl Zeiss) scanning electron microscope (SEM) fitted with an HKL NordLys (Oxford Instruments) EBSD system and using a FastScan (Brucker) atomic force microscope (AFM) in the semi-contact mode.

The DOE was characterized optically using a Polar-1 polarized-light microscope (Mikromed) in the reflection mode and an LSM 780 (Carl Zeiss) confocal microscope. The Raman spectra were also measured according to the procedure outlined in [15]. Sample transmission in the visible range was determined using an AvaSpec-2048 (Avantes) fiber-optic spectrometer. The DOE diffraction patterns were analyzed by probing with a helium–neon laser at a wavelength of 632.8 nm.

Simulations of the depth–concentration profiles of implanted boron with an energy of 40 keV in diamond with SRIM-2013 showed that boron atoms accumulate in a near-surface diamond layer ~100 nm thick, and go no deeper.

RESULTS AND DISCUSSION

Figure 1 shows the optical (Fig. 1a) and SEM (Fig. 1b; angle of observation, 70°) images of the grating formed on the diamond surface via boron implanta-